AN INVESTIGATION OF THE PROBLEM
OF OPTIMIZING A SEARCH TACTIC
FOR A SEARCHLIGHT TYPE SONAR

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THESIS

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by

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An Investigation of the Problem of Optimizing a Search Tactic for a Searchlight Type Sonar

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ABSTRACT

A searchlight type sonar is one of the systems that small navies use to counteract the danger which submarines present to their lines of supply and transport.

In this paper, a standard search pattern for this type of sonar is compared with search patterns which are based on a consideration of the tactical value of detecting a submarine as a function of the relative location of the submarine.

The results of the comparison suggest that is possible to increase the effectiveness of a searchlight type sonar by using a search pattern in which the sweep time allocated to a search sector is based on the sectors tactical importance.

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I. INTRODUCTION

Antisubmarine Warfare (ASW) training constitutes a major part of many navies peacetime training. One reason for this is that the ability to transport troops and supplies by sea during wartime could be a decisive factor in determining the outcome of the conflict.

Several ways exist for navies to improve their ASW capabilities other than to obtain new ASW sensors and weapons systems; one of these is to develop improved tactics for use with their existing systems.

An important ASW sensor system is shipboard mounted active sonar. Two types of active shipboard sonar systems which are in use today in some small navies are the searchlight type sonar system and the scanning type sonar system. In the former, a sound pulse is transmitted into and echoes are received from a narrow sector in a given direction. The area surrounding the ship must be searched in steps, sector by sector. In the scanning sonar, a sound pulse is transmitted and echoes are received in an omnidirectional way. The area surrounding the ship is searched on each pulse.

For the searchlight type sonar, the operator has control of the pattern to be followed in searching the sectors surrounding the ship. In this paper, an investigation of patterns for a searchlight type sonar which tend to optimize detection in certain prefered sectors is made by using computer simulation techniques.

II. NATURE OF THE PROBLEM

The problem of finding an optimum search pattern for a searchlight type detection system was addressed by Koopman (Ref. 1). As a measure of effectiveness, Koopman used W, the effective sweep width, and he concluded that when the instantaneous probability of detection during dt is λdt, assuming no previous detection, and $\lambda = \lambda_1(r)/_r2$, where $\lambda_1(r)$ decreases with increasing r, the search pattern which maximizes the probability of detection for an infinite straight line encounter model consists in fixing the line of sight (or sonar beam) directly along the axis of abscissas, dividing the time equally between the right and the left axis. He made the following remark "It would be misleading to conclude that scannings should always be confined to the beam. In most cases, it is imperative to detect the target early..."

In this paper, some search patterns, which consider the tactical value of detecting a submarine as a function of its relative location are investigated.

A standard pattern for searching with a searchlight sonar is to start on the starboard beam and, after the first emission or "ping" is sent out, train the projector ten degrees toward the bow, send the second "ping", again train ten degrees toward the bow, etc., until the projector is aimed directly toward the bow. From that position, the projector is then trained to the port beam and the above procedure is repeated.

The time between pings is determined by the range scale selected by the operator which is usually the maximum range for the equipment.

In order to compare this search pattern with other patterns, an area around the ship was divided into sectors as shown in Fig. 1. The semicircular boundary of the area is at a distance r_{max} from the ship and it is called the maximum range of the sonar. It will be defined more explicitly on page 12.

In each sector, for the purpose of illustrating the approach being considered here, a somewhat arbitrary relative value for the detection of a submarine in the sector was assigned. The value was intended to indicate the effectiveness of a detection in the sector in preventing a submarine from completing its mission. The rationale supporting the relative values was in part as follows: a submarine detected in Sector B is in a favorable position to be attacked, while a detection in Sector C provides only a minimum time to attack. A detection in Sector A is intermediate in value to detections in Sector B and Sector C.

To make the comparison between the standard pattern and the pattern to be considered here, no search effort was assigned aft of the beam, also a minimum range of detection for a sonar will be assumed. These considerations are the basis for defining Sector D in which no detection can occur. If an application of the approach considered here were to be made, the numbers of sectors, their limits and values attached to them should be determined by specific tactical considerations.

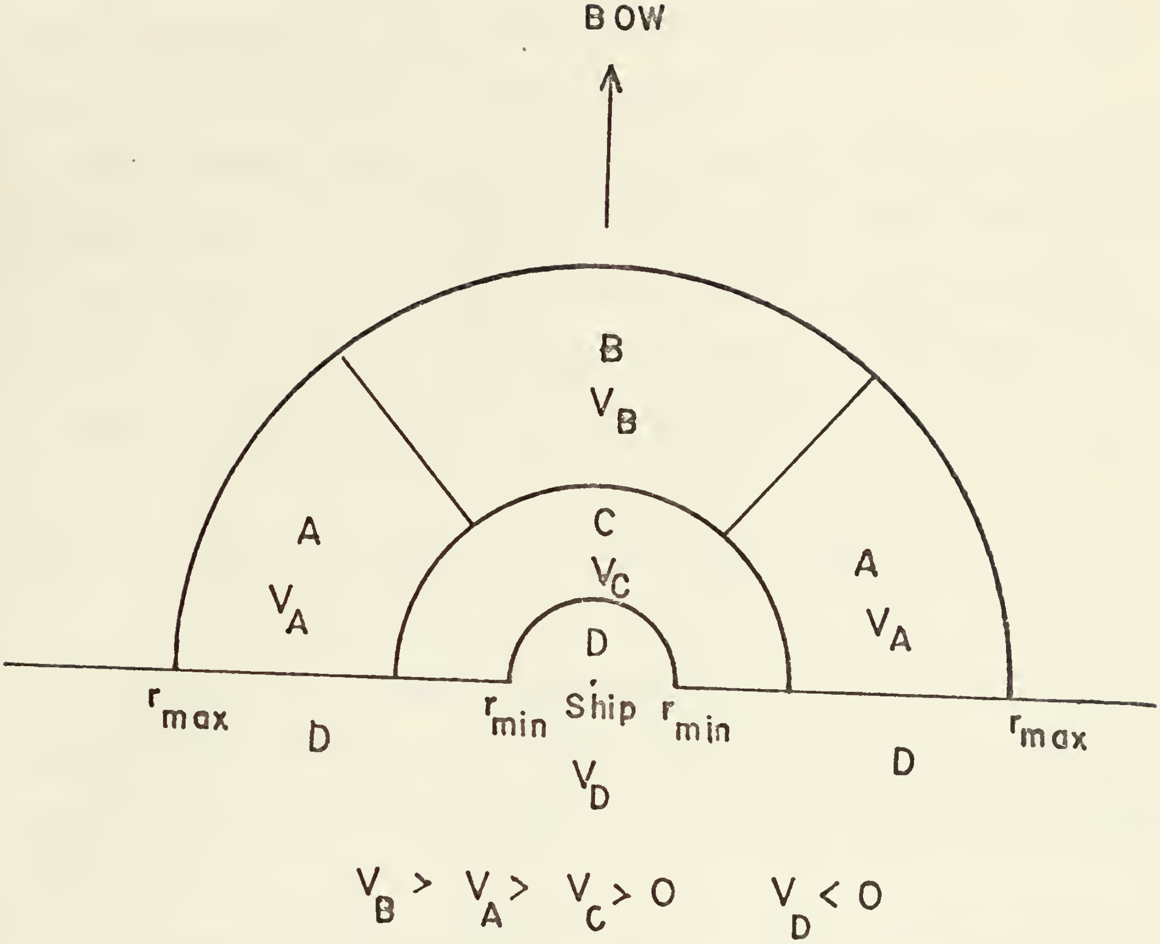

FIGURE 1. SEARCH SECTORS WITH THEIR RELATIVE VALUES

A. MATHEMATICAL MODEL

The values which have been assigned to the different sectors have the following order $V_B > V_A > V_C$ and they will now be specified as being all positive.

A negative V_D was assigned to the event the target reaches Sector D, that is, the event the target enters the sonar search area but is not detected.

The problem then is to try to maximize the expected value of the value of detection by choice of the sweep pattern.

To obtain the detection probability on a single ping, a model which is outlined by Urick (Ref. 2) was used.

The sonar equation, as given by Urick is

$$(1) \qquad 10 \log S/N_o = SL - 2TL + TS - (NL - DI)$$

where S/N_o is the signal-to-noise ratio, TL is the transmission loss, TS is the target strength, SL is the source level, NL is the noise level and DI is the receiving directivity index.

In simple sonar detection models, S/N_o is related to the probability of detection p_d and the false alarm probability p_f. If a false alarm probability is specified, then the probability of detection becomes a function of the signal-to-noise ratio alone. By using this function and the sonar equation, the probability of detection can be expressed as a function of the transmission loss, the source level, the target strength, the noise level and the directivity index.

The transmission loss is a function of the range of the target and for a given range r in yards it is assumed here to be given by

$$(2) \qquad TL = 20 \log r + \alpha r 10^{-3}$$

where the first term represents a spherical spreading loss and in the second term α is in units of decibels per kiloyard and the second term represents absorption loss.

Given such a relation between TL and range r of a target and values for SL, TS, NL and DI and a relation between the probability of detection p_d and the signal-to-noise ratio S/N_o, the probability of detection p_d for a single ping can be expressed as a function of the range to the target, that is the relation $p_d = p_d(r)$ can be found.

To determine such a relation, the characteristics assumed for the searchlight type sonar were the following: an output of 1000 watts of acoustic power, a beam width of 16 degrees, a pulse length of 0.1 sec at a frequency of 10 kHz. and a receiver bandwidth of 500 Hz. The sonar was assumed to be hull mounted on a destroyer traveling at 18 knots. The angular width of the beam was defined as the angle between the 3 db. down rays.

The sonar equation is often written as

$$(3) \qquad TL = 1/2 \; (SL + TS - NL + DI - DT)$$

where DT = 10 log $(S/N_o)_{op}$ and $(S/N_o)_{op}$ is the signal-to-noise ratio required to achieve some operating point, that is, to achieve a particular pair of values of (p_f, p_d). The significance of the equation in this form is that it relates the values of TL, SL, TS, NL and DI to a particular signal-to-noise ratio and, hence, when a relation between S/N_o and p_f and P_d have been specified, to a particular operating point. For example, if an operating point (p_f, p_d) is desired and a relation between S/N_o, p_f, and p_d and values of SL, TS, NL and DI are specified, then the value of TL which will give the desired operating point can be found. The value of p_d at the operating point is often said to be the value required in order that the target will be "just detectable".

In this paper, it will be assumed that if p_d is less than .1, then it is in effect zero. This implies that, for a given p_f, there is a maximum range of detection r_{max} if p_d is a non-increasing function of the range, which will be the case for the model used here.

A value for p_f was chosen by specifying that the probability of more than two false alarms in one hour was .1. This implies the value of p_f is $1\ (10)^{-5}$. This is shown in Appendix A.

The Source Level can be expressed as (Ref. 1, p. 63)

$$SL = 71.5 + 10 \log P + DI_T.$$

For an acoustic power of 1000 w and a DI_T = 20 db for the

central ray of the beam, SL = 118.5 db where the reference level is $0.64(10)^{-12}$ watt/cm^2. From reference 1, Fig 11.10, the self noise level NL for a destroyer at 18 knots is -40 db at 25 kHz.

A noise level slope of -6 db/octave will be assumed in this paper. To compute the value of NL at 10 kHz, consider the following argument. Let x represent the number of octaves between 10 kHz and 25 kHz, then

$$2^x = f_1/f_2 = 2.5$$

and x = 1.32. Hence at 10 kHz

$$NL = -40 - (-6)(1.32) = -32.08 \text{ db}.$$

The target will be assumed to be a submarine at bow aspect with target strength TS = + 10 db (Ref. 1, Table 9.2).

The following model was adopted to relate signal-to-noise ratio to p_f and p_d (Ref. 4)

(4) $$p_d = 1 - \Phi(v_t - \sqrt{d})$$

(5) $$p_f = 1 - \Phi(v_t)$$

(6) $$d = wt\ (S/N)^2$$

where w is the bandwidth, t is the pulse length and $N = wN_o$. For a given value of p_f which in this case is $1 \cdot (10)^{-5}$, v_t is determined by equation (5), and with v_t and given values of w and t, p_d became a function of S/N_o through equation (6) and (4).

This model corresponds to that for a narrow band gaussian signal in gaussian white noise where $S/N << 1$. The function $p_d = p_d(r)$ could be defined by first computing values of TL for various values for r by using equation (2) and then using equation (1) to compute values of 10 log S/N_o. With these values and equation (6) values of d could be computed and with the value of v_t obtained from equation (5), the values of p_d which corresponded to the various values of r could be determined by using equation (4).

Because of the way the function was to be used, particular values of p_d were first specified and then values of r which corresponded to them were determined. These values, along with the corresponding values of TL are listed in Table 1.

The value adopted for r_{max} is that determined by the operating point $\{1(10)^{-5}, .1\}$.

Since the sonar equipment of the type being considered here is usually limited in its detection capability for targets at very close range, a minimum detection range r_{min} of 200 yards was adopted in the model.

To simplify the problem, it was assumed that the target was a point target and that if a target is in the beam for m pings, the probability of detecting it is

$$P\ \{\text{Detection}\} = 1 - \prod_{i=1}^{m} \{ 1 - p_d(r_i) \}$$

where both m and r_i are determined by the relative track of the target through the area scanned by the sonar beam.

As a further simplification, the targets track was assumed to be parallel to the ships track, so that a target will enter

TABLE 1

P_d	TL (db)	r (yards)
0.1	77.11	1749.9
0.2	76.81	1724.9
0.3	76.62	1709.2
0.4	76.47	1696.8
0.5	76.34	1686.1
0.6	76.21	1675.4
0.7	76.09	1665.6
0.8	75.95	1654.1
0.9	75.77	1633.8

Table 1. Values of the transmission loss and range for particular values of the probability of detection and a false alarm probability such that the probability of more than two false alarms in a one hour period is equal to .1.

the semicircular area swept by the beam if its lateral range x is such that $|x|<r_{max}$.

In order to determine the number of scans m on a target during its straight line encounter with the searcher, the sonar position in its search cycle at the moment the target crosses the semicircular boundary must be specified. In addition, the targets lateral range, sonar scanning period and the sweep pattern must be specified. It is reasonable to assume that given the target enters the search area, its lateral range is a random variable which is uniformly distributed between $-r_{max}$ and r_{max} and that the target crosses the line which is tangent to the semicircular area swept by the beam and parallel with the x-axis at a time which is uniformally distributed over the time for a complete scan cycle.

Even with the above assumptions, the problem of determining the average of the value for a pattern is difficult to handle analytically. However, a Monte Carlo simulation can provide a satisfactory solution to this problem.

In this investigation, a computer was used to do a Monte Carlo simulation in order to estimate the expected value of the value for some patterns.

This simulation and its results are discussed in the remainder of the paper.

III. DESCRIPTION OF THE SIMULATION

A search pattern which might be a realizable optimum one under the assumed conditions can be described as follows: start with one normal sweep beam to beam, and then allocate one partial sweep between the rays which bound Sector B. This will be called a 2/1 search pattern since Sector B is searched twice for each search of Sector A. Using this terminology, the standard search pattern would be called a 1/1 search pattern. By allocating additional partial sweeps to Sector B, the search patterns 3/1, 4/1, etc., are generated.

It has been assumed that a submarine can enter the sonar area of detection at any position of the projector and at any lateral range. To simulate this, a target was generated at random on a line parallel to the x-axis and tangent to the semicircular area swept by the beam each time the projector was advanced to a new position.

To reduce starting transient effects and to allow each target an opportunity to be detected, the search process was not started until the first target generated had advanced approximately 1750 yards and the last target generated was allowed to travel the same distance before the search process stopped.

The simulation was run for the search patterns 1/1, 2/1. 3/1, 4/1, and 5/1 with 500 targets generated for each pattern. Ten different runs of each pattern were made in order to obtain a statistically adequate sample.

The sectors chosen and the detection values assigned to them were as follows, where bearings are relative to the heading of the ship: Sector A: between bearings 040° and 090° and between 270° and 320° and between ranges of 800 and 1800 yards. Value: 2. Sector B: between bearings 320° and 040° and between ranges of 800 and 1800 yards. Value: 10. Sector C: between bearings 270° and 090° and between ranges of 200 and 800 yards. Value: 1. Sector D: between bearings 270° and 090° and between ranges of 0 to 200 yards and all the area aft of the x-axis. Value: -1.

The geometry used for the simulation is shown in Fig. 2. The ship is at the origin of a system of rectangular coordinates which is moving in the positive direction of the y-axis at a speed of 18 knots.

As only positive values of x need to be considered because of the symmetry of the sectors and sweep patterns, the area of interest for the simulated search is the positive quadrant and targets were uniformly generated on the positive section of the line parallel to the x-axis. This section of the line is 1800 yards long and it is 1800 yards from the ship. The value 1800 was used since it is a little larger than the range corresponding to $p_d = 0.1$ which was arbitrarily said to be equivalent to $p_d = 0$.

The targets moved in the negative direction of the y-axis and parallel to it at a speed of 10 knots, so that their relative speed during an encounter was 28 knots. Both ships kept their courses and speed constant.

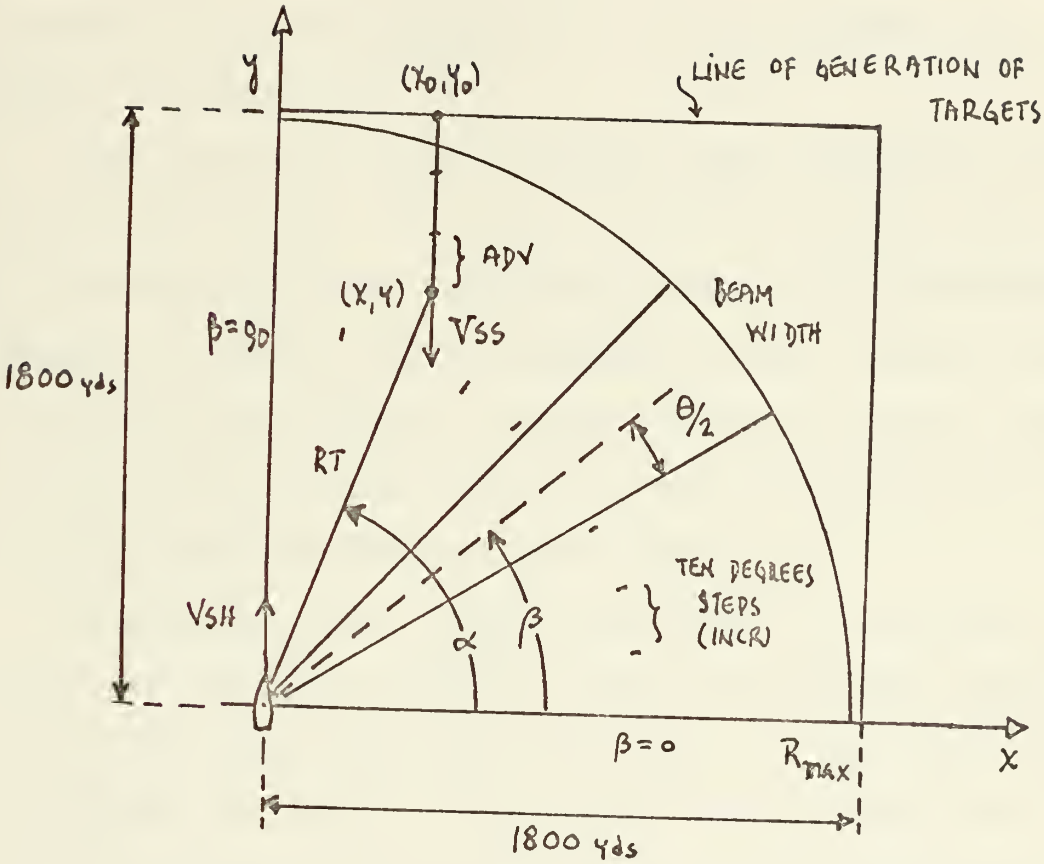

FIGURE 2. GEOMETRY OF THE SIMULATION

The name of the variables and data used are given in Appendix B and the schematic flow chart is shown in Fig. 3.

The matrix TAR and vector ITAR were used to keep the parameters of each target generated. The coordinates of the position of the target were kept in TAR. The condition of the target was said to be active if it was in the detection area and not detected and passive if it was in the detection area and detected or if it had crossed into Sector D undetected.

When the search process starts, the first ping is on the starboard beam, for each ping after the first ping, the projector is trained 10 degrees and the target advanced downward 35 yards which corresponds to the relative distance traveled by the target in a time interval equal to that necessary for a sound pulse to go to 1800 yards and return. A sound speed of 4800 ft/sec was used.

On each ping, the angular positions of the active targets were computed and compared in order to determine those, if any, which were inside the sonar beam. A beam width of 16 degrees was used. All of those targets which were outside of the beam could not be detected and they were advanced downward. If a target was inside the beam, its range to the ship was computed. If this range were less than the minimum range of 200 yards, no detection was possible and the target was then assigned to Sector D.

For targets whose ranges were greater than the minimum, the transmission loss to the target was computed and the probability of detection was obtained. If this probability

was less than 0.1, no detection occurred and the target was advanced.

To determine if a detection event occurred, a random number, uniformly distributed (0,1), was generated and if the random number was less than the probability of detection a detection occurred. Otherwise a detection did not occur. Detections were assigned to the sectors in which they occurred.

After the above process was completed, the projector was trained, a new ping emitted and the process was started again.

Whenever the projector reached the position in which it was trained toward the bow of the ship, the search on the port side was simulated. This was done by executing the generation and advance of the targets in the positive quadrant for the numbers of pings required to cover the port side for the pattern being used. Detection of targets could not be made during the period necessary to generate these pings. The above procedure was possible because of the port/starboard symmetry of the problem.

The targets which crossed the area without being detected were assigned to Sector D.

The search pattern execution was controlled by the part of the program labelled Control of the Search Sweep Pattern. It essentially counted the times the projector went into each sector and produced the desired sweep ratio. This section also controlled the simulated search on the port side.

When the five search patterns had been realized, a new run for all the sweep patterns was executed.

The detection values obtained for each sweep pattern are kept in the matrix STORE. This matrix and the average of the value and standard deviation of the value for each pattern was the output of the simulation.

The outputs of a given search pattern for the ten different runs can be considered to be samples from the population of values for that sweep pattern.

The Mann-Whitney test was performed with the data in the matrix STORE and the result was printed.

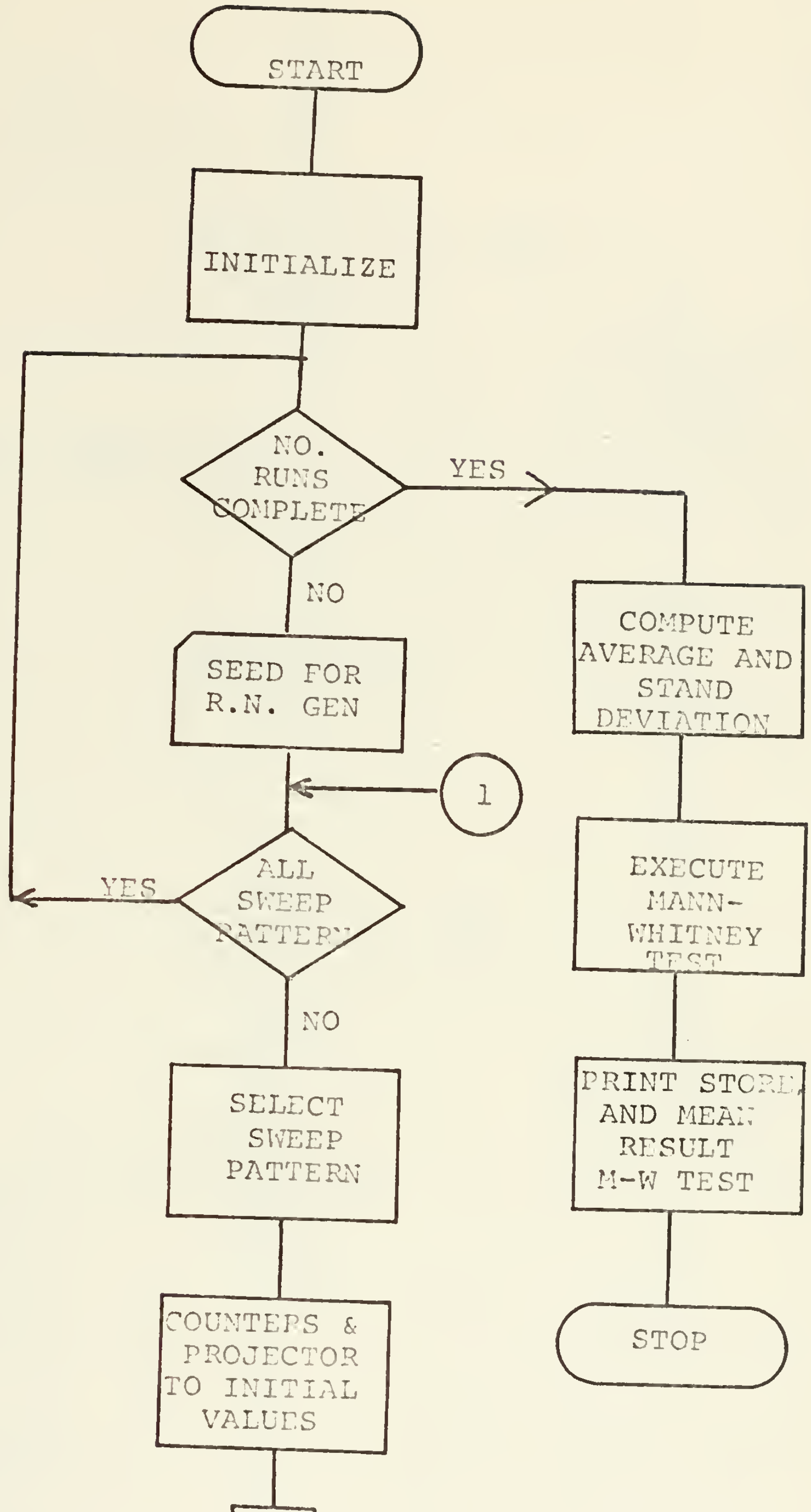

FIGURE 3. SCHEMATIC FLOW CHART (1)

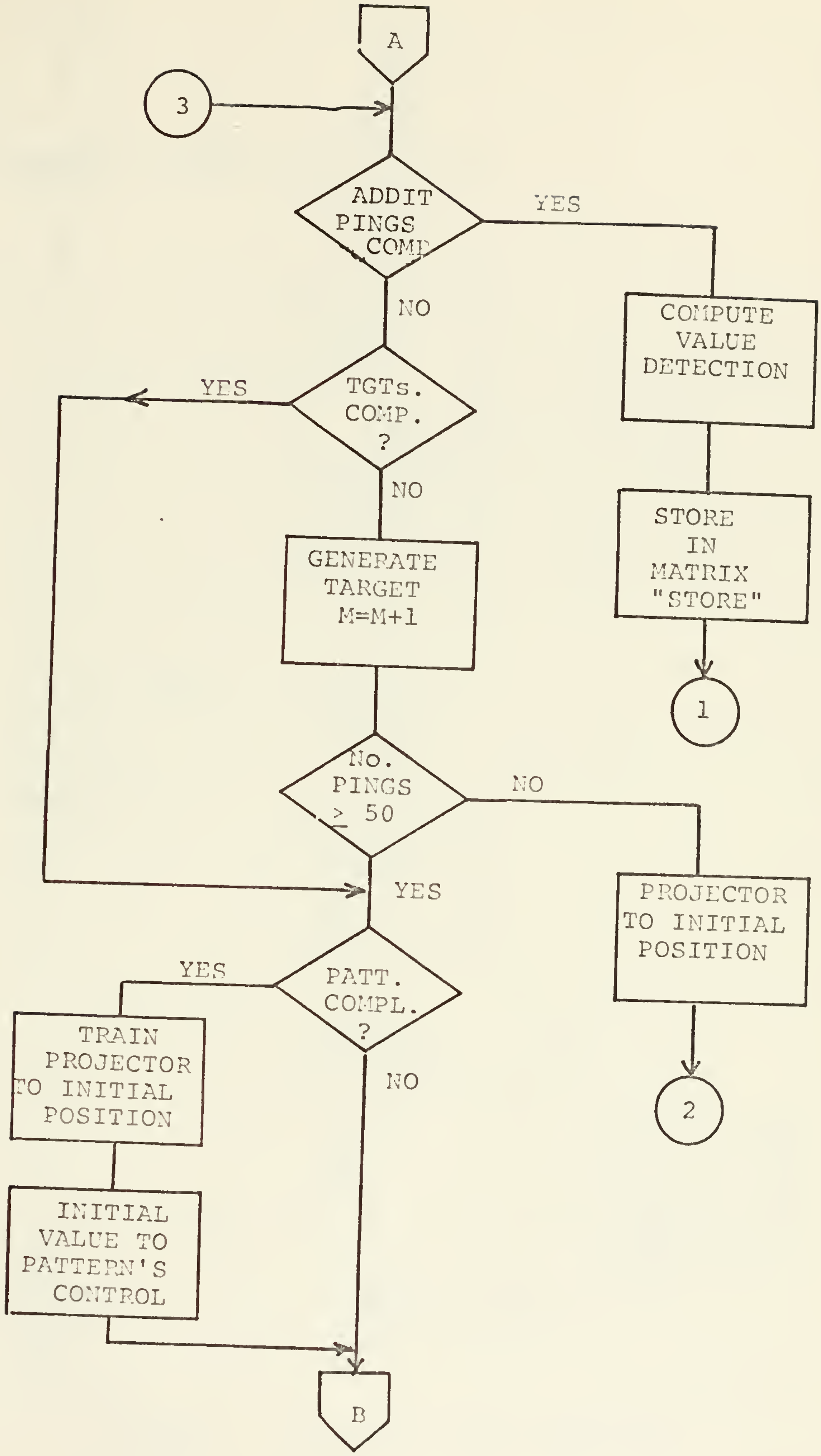

FIGURE 3. SCHEMATIC FLOW CHART (2)

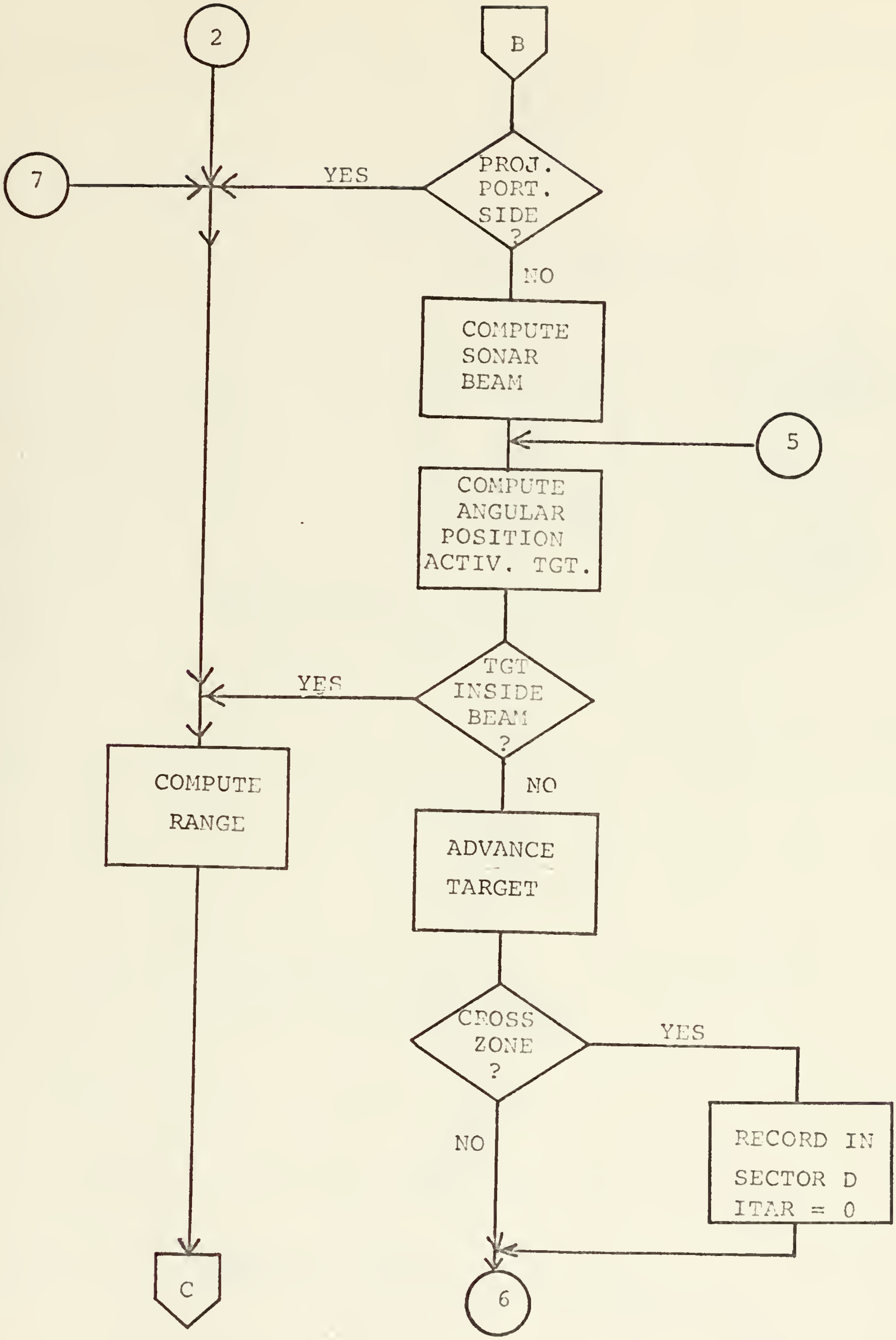

FIGURE 3. SCHEMATIC FLOW CHART (3)

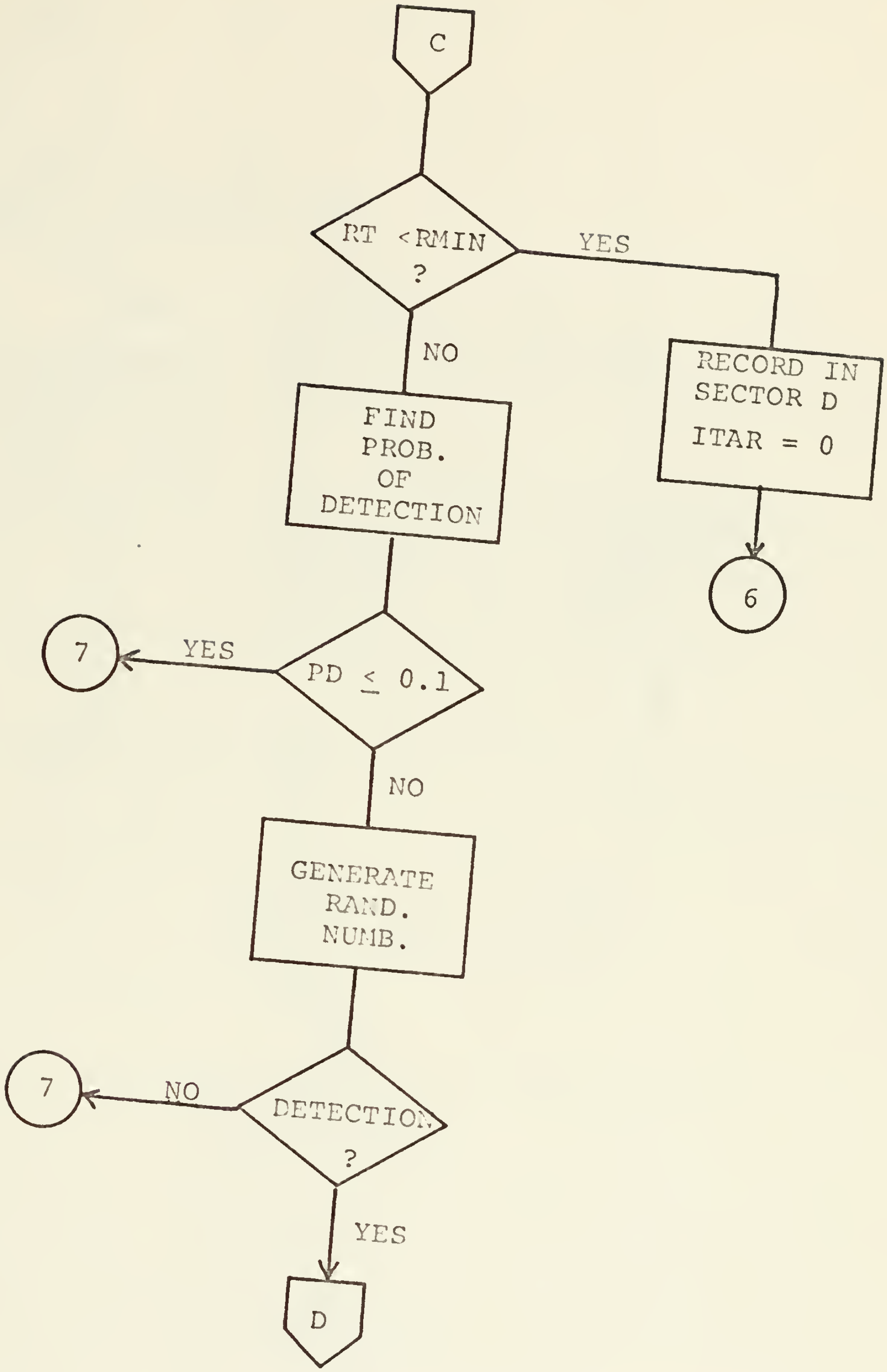

FIGURE 3. SCHEMATIC FLOW CHART (4)

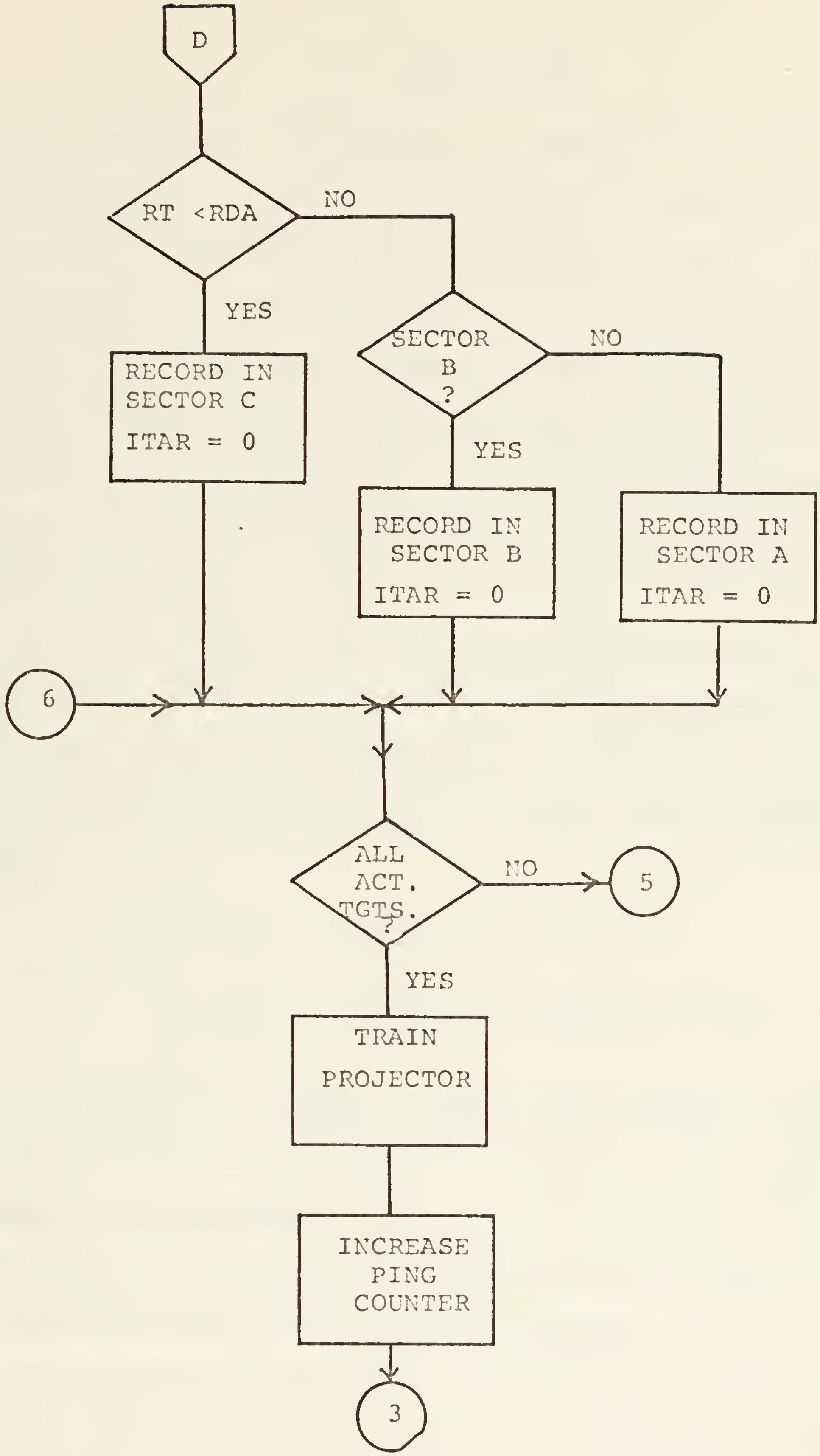

FIGURE 3. SCHEMATIC FLOW CHART (5)

IV. CONCLUSIONS

The averages of the values of detection for the five sweep patterns investigated and for the assigned values suggested in some cases that the expected value of the value of detection is different than that of the 1/1 standard pattern. To test this conjecture, the Mann-Whitney test was used. This test was used because it is nonparametric, the distribution of the value of detection was not known, and the sample size was not large enough to assume a normal distribution.

The Mann-Whitney test (Ref. 3) with the assumption that if there is a difference between population distribution functions, then that difference is a difference in the means of the distributions allows one to make the following hypothesis:

$$H_0 \; : E\{X(1/1)\} \geq E\{Y(n/1)\}$$

$$H_1 \; : E\{X(1/1)\} < E\{Y(n/1)\}$$

where $X(1/1)$ is the random variable representing a value from the population of values of detection with the (1/1) standard search pattern and $Y(n/1)$ is the random variable representing a value from the population of values of detection obtained with a (n/1) search pattern.

If the null hypothesis is accepted, that is if the expected value of X is greater than or equal to the expected value of Y, this means that at the level of significance

chosen, there is not a significant improvement in the value of detection with that pattern. If the null hypothesis is rejected, this means that there is a significant improvement by using that sweep pattern.

For the test, a 90% confidence level was chosen.

The Mann-Whitney test results are given in Table II below.

TABLE II

RESULT OF MANN-WHITNEY TEST

VALUE OF T STATISTIC 50.00

FOR SWEEP PATTERN 1/1 ACCEPT H_0

VALUE OF T STATISTIC 43.50

FOR SWEEP PATTERN 2/1 ACCEPT H_0

VALUE OF T STATISTIC 36.00

FOR SWEEP PATTERN 3/1 ACCEPT H_0

VALUE OF T STATISTIC 32.00

FOR SWEEP PATTERN 4/1 REJECT H_0

VALUE OF T STATISTIC 34.50

FOR SWEEP PATTERN 5/1 ACCEPT H_0

It should be noted again that the above results were obtained with arbitrary sectors and arbitrary sectors values of detection and that the encounters were particular straight line encounters. In addition, the assumed characteristics of the sonar equipment was specific and the relation between TL and r was restrictive.

Estimates of the probability that a target which enters a search pattern will be detected can be made as follows: Assign the values $V_A = V_B = V_C = 1$ and $V_D = 0$ and then divide the average of the values which are obtained from the simulation by the number of targets generated in the simulation. The resulting numbers are the estimates. Estimates for the five sweep patterns investigated are given in Table III.

TABLE III

ESTIMATES OF THE PROBABILITY OF DETECTION

Sweep Pattern	Est. Prob. of Detection
1/1	0.91
2/1	0.89
3/1	0.85
4/1	0.82
5/1	0.79

APPENDIX A

Determination of False Alarm Probability.

Since p_d and p_f apply to a resolution cell and the resolution cell's size in time is equal to the pulse length, in one hour $n = 3600 / .1 = 36000$ resolutions cells will be sampled.

If independence is assumed and if X represents the number of false alarm in one hour period then the probability of less than two false alarms in one hour is

$$P\,[X\leq 2] = \sum_{k=o}^{2} \binom{n}{k} p_f^k (1-p_f)^{n-k}$$

$$= (1-p_f)^n + \frac{n!}{(n-1)!} p_f (1-p_f)^{n-1} + \frac{n!}{(n-2)!2!} p_f^2 (1-p_f)^{n-2} .$$

Since $p_f \ll 1$ and $n \gg 1$

$$P\,[X\leq 2] \simeq (1-p_f)^n + n\, p_f\, (1-p_f)^n$$

$$\simeq (1-p_f)^n \{1+n\, p_f\}$$

$$\simeq (1-np_f)(1-np_f)$$

$$\simeq 1 - n^2 p_f^{\,2} .$$

Hence, $p_f^2 = \frac{1 - P[X\leq 2]}{n^2}$ and if $P[X\leq 2] = .9$, that is,

$$P\,[X>2] = .1 \text{ then}$$

$$p_f \simeq 0.8784.10^{-5} \text{ or}$$

$$p_f \simeq 1.10^{-5} .$$

APPENDIX B

VARIABLES AND DATA IN THE PROGRAM

DATA

NSS	=	Number of targets generated
RMAX	=	Maximum sonar search range
ATT	=	Attenuation factor for propagation
LUPA	=	Upper limit of Sector A (starboard side)
LLUPA	=	Upper limit of Sector A (port side)
IX	=	Seed for random number generator
LIM	=	Numbers of additional targets generated (LIM=NSS+50)
YS	=	y distance of generation of target
RMIN	=	Minimum sonar detection range
RDA	=	Upper range limit of Sector C
VSH	=	Speed of the ship
VSS	=	Speed of the submarine (target)
VSO	=	Speed of sound
ITETA2	=	Half beam width
INCR	=	Step in train of the projector
NUM	=	Number of runs
JN	=	Increment in number of ping.
TTAB	=	Value of table for Mann-Whitney test
WEn	=	Value of detection in Sector n (A,B,C,D)
MOSn	=	Required number of sweep in Sector n (A,B)
TLxx	=	Transmission loss corresponding to 0.xx prob. of detection

VARIABLES

IBETA	= Angular position of projector
IBEUB	= Upper ray of sonar beam
IBELO	= Lower ray of sonar beam
ALFA	= Angular position of the target
ADV	= Advance of target in each inter ping time
PD	= Probability of detection
YFL	= Random number U(0.1)
TL	= Actual transmission loss
RT	= Range of target
M	= Number of targets actually generated
IGEN	= Counter for number of pings
T	= Time between pings
TWEn	= Total value of detection in Sector n
TTW	= Total value of detection
NOn	= Number of detections in Sector n
NOSn	= Counter to control sweep pattern
T	= Statistic of Mann-Whitney test

MATRICES AND VECTORS

STORE (I,J)	= Value of detection for run I and sweep pattern J
VALUE (J)	= Average value of detection for sweep pattern J
SIGMA (J)	= Standard deviation for value of detection of pattern J
TAR (K,L)	= Data of each target K

$\begin{cases} (K,1) \text{ x coordinate of target K} \\ (K,2) \text{ y coordinate of target K} \end{cases}$

ITAR (K) = Condition for each target K

$\begin{cases} 1 = \text{Target in the area undetected (Active)} \\ 0 = \text{Target detected or crossed the area undetected (Passive)} \end{cases}$

A(I) = Data of run (I) for Mann-Whitney test

R(I) = Working vector for Mann-Whitney test

SUBROUTINES

RANK = Subroutine IBM to rank a vector of values

RANDU = Subroutine IBM to generate a random number U(0.1)

COMPUTER OUTPUT

MATRIX OF VALUES OF DETECTION

RUNS	SWEEP PATTERNS				
	1/1	2/1	3/1	4/1	5/1
1	2959.00	2590.00	2684.00	2825.00	2812.00
2	2748.00	2760.00	2831.00	2837.00	2766.00
3	2853.00	2786.00	2823.00	2713.00	2781.00
4	2780.00	2799.00	2791.00	2678.00	2811.00
5	2587.00	2707.00	2934.00	2849.00	2866.00
6	2590.00	2684.00	2825.00	2812.00	2775.00
7	2760.00	2831.00	2837.00	2776.00	2788.00
8	2786.00	2823.00	2713.00	2871.00	2806.00
9	2779.00	2791.00	2678.00	2811.00	2566.00
10	2707.00	2934.00	2849.00	2886.00	2779.00

S.PATT	AV.VALUE	STD.DEV
1/1	2754.899	111.160
2/1	2768.499	93.123
3/1	2796.499	81.451
4/1	2805.799	66.491
5/1	2786.999	86.660

RESULT OF MANN-WHITNEY TEST

VALUE OF T STATISTIC 50.00
FOR S.PATTERN 1/1 ACCEPT HO

VALUE OF T STATISTIC 43.50
FOR S.PATTERN 2/1 ACCEPT HO

VALUE OF T STATISTIC 36.00
FOR S.PATTERN 3/1 ACCEPT HO

VALUE OF T STATISTIC 32.00
FOR S.PATTERN 4/1 REJECT HO

VALUE OF T STATISTIC 34.50
FOR S.PATTERN 5/1 ACCEPT HO

COMPUTER PROGRAM

```
C     SIMULATION OF SEARCH AND DETECTION OF A
C            SEARCHLIGTH TYPE SONAR

      DIMENSION TAR(550,2),ITAR(550)
      DIMENSION STORE(5,10),IO(5),VALUE(5),SIGMA(5)
      DIMENSION A(20),R(20)
      DATA TAR/1100*0.0/,ITAR/550*0/,IO/1,2,3,4,5/
      DATA STORE/50*0.0/,VALUE/5*0.0/,SIGMA/5*0.0/
      DATA INCR/10/,JN/1/,ITETA2/8/,ATT/7.0/,MOSA/1/
      DATA RMAX/1800.0/,RDA/800.0/,RMIN/200.0/
      DATA VSH/18.0/,VSS/10.0/,VSO/1600.0/,YS/1800.0/
      DATA TL10/77.11/,TL20/76.81/,TL30/76.62/
      DATA TL40/76.47/,TL50/76.34/,TL60/76.21/
      DATA TL70/76.09/,TL80/75.95/,TL90/75.77/
      DATA WEA/2.0/,WEB/10.0/,WEC/1.0/,WED/-1.0/
      NSS=500
      NUM=10
      LUPA=50
      LLUPA=180-LUPA
      T=RMAX*2/VSO
      LIM=NSS+50
      LUM=NUM-1

C      GENERATE RUNS

      DO 7000 KK=1,NUM
      READ(5,8100)IX

C     GENERATE ALL TARGETS FOR EACH SWEEP PATTERN

      DO 2000 JJ=1,5
      MOSB=JJ
      IBETA=0
      NOSA=0
      NOSB=0
      NOA=0
      NOB=0
      NOC=0
      NOD=0
      M=0
      IGEN=1

C     TARGETS ARE GENERATED AT ALL POSITIONS OF THE BEAM

  180 M=M+1
      IF(M.GT.LIM) GO TO 1900
      IF(M.GT.NSS) GO TO 210

C     GENERATE TARGET UNIFORMLY DISTRIBUTED

      CALL RANDU(IX,IY,YFL)
      IX=IY
      TAR(M,1)=YS*YFL
      TAR(M,2)=YS
      ITAR(M)=1

C    THE SEARCH START FIRST TARGET HAS ADVANCED 50 STEPS
C     APROX 1750 YARDS

      IF(IGEN-50) 1,210,210
    1 IBETA=0
      GO TO 150
```

```
C         CONTROL OF THE SEARCH SWEEP PATTERN

 21J   IF((NOSA.EQ.MOSA).AND.(NOSB.EQ.MOSB)) GO TO 265
       IF(IBETA.LE.90) GO TO 200
       IF((IBETA.GT.90).AND.(IBETA.LE.LLUPA)) GO TO 150
       IF(IBETA.GT.180) GO TO 260
       IF(NOSA.LT.MOSA) GO TO 150

C      SOME SECTOR NEED EXTRA SWEEP

       IBETA=LUPA
       NOSB=NOSB+1
       IF(NOSB.EQ.MOSB)IBETA=0
       GO TO 200

C      BOTH SWEEP COMPLETED, START A NEW CYCLE

 265   NOSA=0
       NOSB=0
       GO TO 200

C     BOTH SECTOR NEED EXTRA SWEEP

 260   NOSA=NOSA+1
       NOSB=NOSB+1
       IBETA=0
       IF(NOSA.EQ.MOSA) IBETA=LUPA
       IF((NOSA.EQ.MOSA).AND.(NOSB.EQ.MOSB)) IBETA=0

C     DETERMINE  POSITION OF THE SONAR BEAM

  200 IBEUP=IBETA+ITETA2
       IBELO=IBETA-ITETA2
       IF(IBELO.LT.0) IBELO=0

C    CHECK IF TARGET IS IN THE BEAM
C      CHECK ALL ACTIVE TARGETS

       DO 120 J=1,M

C      TARGET CROSSED AREA UNDETECTED
C        ASSIGN TO SECTOR D

       IF(ITAR(J)) 120,120,101
 101   IF(TAR(J,2).GT.30.0) GO TO 110
       GO TO 258
  110 ALFA=ATAN(TAR(J,2)/TAR(J,1))*360.0/6.2832
 220   IF((ALFA.LE.IBEUP).AND.(ALFA.GE.IBELO)) GO TO 3JJ

C    ADVANCE TARGET

  25J  ADV=T*(VSH+VSS)*2000.0/3600.0
       TAR(J,2)=TAR(J,2)-ADV
       IF(TAR(J,2).GT.30.0) GO TO 120
       GO TO 258

C    IF TARGET IS IN THE BEAM COMPUTE RANGE

  300 RT=SQRT(TAR(J,1)**2+TAR(J,2)**2)

C     NO DETECTION FOR MINIM.RANGE. ASSIG TO SECTOR D

       IF(RT.LT.RMIN)GO TO 258

C      COMPUTE TRANSMISION LOSS

       TL=20.0*ALOG10(RT)+ATT*RT/1000.0
```

```
C   CHECK TL TO FIND PROB. OF DETEC.
C  ASUME NO DETECTION IF PROB. DETEC IS 0.1 OR LESS

      IF(TL.GT.TL10) GO TO 250
      IF(TL.LT.TL90) GO TO 410
      IF(TL.LT.TL80) GO TO 420
      IF(TL.LT.TL70) GO TO 430
      IF(TL.LT.TL60) GO TO 440
      IF(TL.LT.TL50) GO TO 450
      IF(TL.LT.TL40) GO TO 460
      IF(TL.LT.TL30) GO TO 480
      IF(TL.LT.TL20) GO TO 490
      PD=0.1
      GO TO 470
 410  PD=0.9
      GO TO 470
 420  PD=0.8
      GO TO 470
 430  PD=0.7
      GO TO 470
  440 PD=0.6
      GO TO 470
 450  PD=0.5
      GO TO 470
 460  PD=0.4
      GO TO 470
 480  PD=0.3
      GO TO 470
 490  PD=0.2

C     GENERATE  RANDOM NUMBER U(0,1) TO DECIDE DETECTION

 470  CALL RANDU(IX,IY,YFL)
      IX=IY
      IF(YFL.GT.PD) GO TO 250

C     EVENT DETECTION - ASSIGN TO ONE SECTOR

 600  IF(RT.LT.RDA) GO TO 615
      IF(ALFA.LE.LUPA) GO TO 620
C   SECTOR B
      NOB=NOB+1
      GO TO 640
C    SECTOR C
 615  NOC=NOC+1
      GO TO 640
C      SECTOR A
  620 NOA=NOA+1
      GO TO 640

C     SECTOR D
  258 NOD=NOD+1
  640 ITAR(J)=0
 120  CONTINUE
      GO TO 160

C    WHEN BEAM IS AT PORT SIDE,ADVANCE TARGETS IN STBD.SIDE

  150 DO 130 J=1,M
      IF(ITAR(J)) 130,130,140
 140  ADV=T*(VSH+VSS)*2000.0/3600.0
      TAR(J,2)=TAR(J,2)-ADV
C    TARGET CROSSED AREA  NO DETECTION
      IF(TAR(J,2).GT.30.0) GO TO 130
      NOD=NOD+1
      ITAR(J)=0
  130 CONTINUE
```

```
C  ROTATE BEAM

 160   IGEN=IGEN+JN
       IBETA=IBETA+INCR
       GO TO 180

C      COMPUTE VALUE OF DETECTION AND STORE IT

 1900  TWEA=WEA*NOA
       TWEB=WEB*NOB
       TWEC=WEC*NOC
       TWED=WED*NOD
       TTW=TWEA+TWEB+TWEC+TWED
       STORE(KK,JJ)=TTW
 2000  CONTINUE
 7000  CONTINUE

C    COMPUTE MEAN AND STANDARD DEVIATION

       DO 6000 J=1,5
       DO 5000 K=1,NUM
       VALUE(J)=VALUE(J)+STORE(K,J)/NUM
 5000  CONTINUE
       DO 6550 IK=1,NUM
       SIGMA(J)=SIGMA(J)+(STORE(IK,J)-VALUE(J))**2
 6550  CONTINUE
       SIGMA(J)=SQRT(SIGMA(J)/LUM)
 6000  CONTINUE

C    PRINT MATRIX OF VALUE OF DETECTION

       WRITE(6,9999)
       WRITE(6,9990)
       WRITE(6,8500)(IO(J),J=1,5)
       DO 8000 LL=1,NUM
       WRITE (6,8200) LL,(STORE(LL,JK),JK=1,5)
 8000  CONTINUE

C    PRINT MEAN AND STANDARD DEVIATION OF DETECTION VALUES

       WRITE (6,8300)
       DO 6500 J=1,5
       WRITE (6,8400) IO(J),VALUE(J),SIGMA(J)
 6500  CONTINUE

C     MANN - WHITNEY TEST

C         HO: E(VALUE 1/1) GREATER OR EQUAL TO E(VALUE X/1)
C         H1: E(VALUE 1/1) LESS THAN E(VALUE X/1)

C        FOR 90% OF CONFIDENCE (ONE TAIL TEST)

       N1=10
       N2=10
       N=N1+N2
       TTAB=33
       WRITE(6,9000)

C       READ VECTOR SWEEP PATTERN 1/1

       DO 15 J=1,N1
       A(J)=STORE(J,1)
  15   CONTINUE
```

```
C      READ VECTOR TO TEST  (FIRST IS PATTERN 1/1)

       N2=N2+1
       DO 20 I=1,5
       DO 30 IJ=N2,N
       JI=IJ-10
       A(IJ)=STORE(JI,I)
  30   CONTINUE

C     RANK OF VALUES

       CALL RANK(A,R,N)
C     SUM RANK OF FIRST VECTOR

       R2=0.0
       DO 10 M=1,N1
       R2=R2+R(M)
   10  CONTINUE

C    COMPUTE T STATISTIC

       T=R2-N1*((N1+1)/2.0)
       WRITE(6,9010) T
       IF(T.GE.TTAB) GO TO 50
       WRITE(6,9100)I
       GO TO 20
  50   WRITE(6,9200)I
  20   CONTINUE

C           FORMATS

 8100  FORMAT(I9)
 8200  FORMAT (1X,//,14X,I4,5F9.2)
 8300  FORMAT('1',////,20X,'S.PATTERN    AV.VALUE   S.DEV')
 8400  FORMAT(1X,//,24X,I2,8X,2F10.3)
 8500  FORMAT (1X,//,16X,5I9)
 9000  FORMAT('1',/////,25X,'RESULT OF MANN-WHITNEY TEST')
 9010  FORMAT (1X,/////,21X,'VALUE OF T STATISTIC',F10.2)
 9100  FORMAT(1X,/,21X,'FOR S.PATTERN',I2,'/1 REJECT HO')
 9200  FORMAT(1X,/,21X,'FOR S.PATTERN',I2,'/1 ACCEPT HO')
 9990  FORMAT(1X,///,14X,'RUNS',15X,'SWEEP PATTERN')
 9999  FORMAT('1',/////,28X,'MATRIX OF VALUE OF DETECTION')
       STOP
       END
```

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13. ABSTRACT

A searchlight type sonar is one of the systems that small navies use to counteract the danger which submarines present to their lines of supply and transport.

In this paper, a standard search pattern for this type of sonar is compared with search patterns which are based on a consideration of the tactical value of detecting a submarine as a function of the relative location of the submarine.

The results of the comparison suggest that is possible to increase the effectiveness of a searchlight type sonar by using a search pattern in which the sweep time allocated to a search sector is based on the sectors tactical importance.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Sweep Patterns						
Sonar Detection						
Simulation of Searchlight Type Sonar Detection						

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